PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : **H01J 37/04, 37/28** — A1

(11) International Publication Number: **WO 99/26272**

(43) International Publication Date: 27 May 1999 (27.05.99)

(21) International Application Number: PCT/EP98/07381

(22) International Filing Date: 17 November 1998 (17.11.98)

(30) Priority Data:
97120124.9 17 November 1997 (17.11.97) EP

(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(71) **Applicant** *(for all designated States except US)*: ICT INTEGRATED CIRCUIT TESTING GESELLSCHAFT FÜR HALBLEITERPRÜFTECHNIK MBH [DE/DE]; Ammerthalstrasse 20, D-85551 Heimstetten (DE).

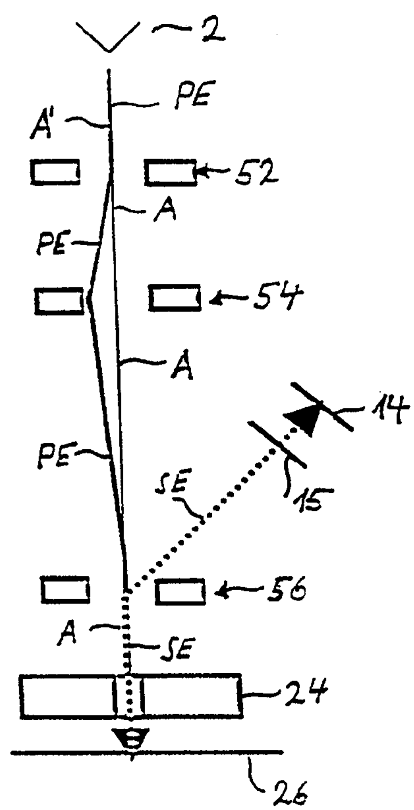
(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: FEUERBAUM, Hans-Peter [DE/DE]; Arno-Assmann-Strasse 14, D-81739 Munich (DE). WINKLER, Dieter [DE/DE]; Arno-Assmann-Strasse 9, D-81739 Munich (DE). DEGENHARDT, Ralf [DE/DE]; Am Römerbrunnen 12, D-85609 Aschheim (DE). MUNACK, Harry [DE/DE]; Graf-Andechs-Strasse 10, D-85551 Heimstetten (DE).

(74) **Agents:** DIEHL, Hermann, O., Th. et al.; Augustenstrasse 46, D-80333 Munich (DE).

(54) **Title:** PARTICLE BEAM DEVICE

(57) **Abstract**

This invention relates to a particle beam device comprising a primary particle source (2) for providing a primary particle beam and a specimen onto which the primary particle beam impinges in a certain direction thereby producing secondary particles. It further comprises optical devices for directing particles from source to specimen, and a detector (14) for secondary particles being arranged outside of the primary particle beam path. The primary particle beam runs diagonally to the optical axis and is then guided onto the optical axis by a redirection unit (56).



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece	**ML**	Mali	**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**MN**	Mongolia	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MR**	Mauritania	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MW**	Malawi	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MX**	Mexico	**US**	United States of America
CA	Canada	**IT**	Italy	**NE**	Niger	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NL**	Netherlands	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NO**	Norway	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NZ**	New Zealand	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**PL**	Poland		
CM	Cameroon	**KR**	Republic of Korea	**PT**	Portugal		
CN	China	**KZ**	Kazakstan	**RO**	Romania		
CU	Cuba	**LC**	Saint Lucia	**RU**	Russian Federation		
CZ	Czech Republic	**LI**	Liechtenstein	**SD**	Sudan		
DE	Germany	**LK**	Sri Lanka	**SE**	Sweden		
DK	Denmark	**LR**	Liberia	**SG**	Singapore		
EE	Estonia						

PARTICLE BEAM DEVICE

FIELD OF THE INVENTION

This invention relates to a particle beam device comprising a primary particle source for providing a primary particle beam, a specimen onto which the primary particle beam impinges in a direction thereby producing secondary particles, optical devices for directing particles from source to specimen, and a detector for secondary particles being arranged outside of the primary particle beam path.

BACKGROUND OF THE INVENTION

The above described particle beam device is, in general, known e.g. as scanning electron microscope. The detection of secondary particles is of particular importance since they contain information regarding the specimen to be examined. Primary particles (in general electrons, therefore, without limiting the scope of the invention, the expressions primary electrons or secondary electrons will often be used in the following) have to be separated from secondary particles. Thereby, the primary particle beam should be influenced as little as possible i.e. the resolution of the system should not deteriorate. Further, secondary particles should be completely detected.

In the past, two systems have been used for detectors arranged at the side. In one system, the detector has been arranged within the specimen chamber i.e. between objective lens and specimen. Thereby, disadvantageously, the working distance which is the minimum distance between objective lens and specimen was increased by the secondary electron detector. In addition, a weak field directed sideways is necessary for deflection of secondary particles towards the detector. Both have a negative influence on the smallest achievable diameter of the primary beam which, in turn, determines the resolution of the system.

In many cases, the detector is arranged above the objective lens, in particular in case of objective lenses with superimposed electrostatic and magnetic fields. If the detector is arranged on the side, then the secondary electrons are deflected from the optical axis towards the detector using a Wien-filter characterized by crossing E and B fields. However, a Wien filter requires extensive care and is difficult to adjust.

SUMMARY OF THE INVENTION

The invention therefore provides a particle beam device which uses a simple but effective arrangement to separate secondary electrons from primary electrons and influences resolution of the primary electron beam as little as possible.

This object is achieved by means which cause the primary particle beam to run diagonally to the optical axis and by deflection means arranged below the detector for redirecting the primary particle beam into the optical axis.

The expressions "below" and "above" are used in the context that the source is provided "above" the specimen which is usually the case.

The invention provides, in particular, the following advantages: The primary particle beam having a path diagonal to the axis requires a redirection unit. However, the redirection unit can be very simple i.e. much simpler than a Wien filter. It also affects secondary particles in the sense that it separates primary and secondary particles. This is regardless of the redirection unit being magnetic or electrostatic which will be explained in further detail below. If the

detector is arranged (lateral) in the direction of the secondary particles being redirected by the redirection unit then these can be detected without much effort. On the other hand, the primary particle beam is hardly influenced. This is in particular true in view of the small angles occurring in practice.

It is preferred to tilt the source and the optical devices arranged above the redirection unit. If source and optical devices (e.g. condenser lens) arranged above the redirection unit are tilted at a selected angle with respect to the axis which normally connects source and specimen then, in a simple manner, it is accomplished that the primary particle beam runs diagonal to this axis. This angular path is corrected by the redirection unit according to the invention which in addition affects the secondary particles in the desired fashion.

Preferably, at least a section of the path of the primary particle beam above the redirection unit is shifted parallel to the optical axis. In that case, a deflection unit for deflecting the primary beam towards the optical axis is provided. In this embodiment, source and optical devices (or a part of it) are not tilted but shifted parallel. The beam parallel to the axis is then directed in a direction angular to and towards the axis by a deflection unit. This deflection unit does not need to be different to the redirection unit of the invention. The deflection unit is provided in addition, still, it requires less effort than the use of e.g. a Wien filter. In addition, it has the advantage that imaging defects (aberration) which might be caused by the redirection can be compensated through the deflection which is opposite to the redirection.

In even more preferred embodiments, the direction of the primary beam coming from the source is essentially the one of the optical axis as defined by the objective lens. In that case there is provided a first deflection for deflecting the primary beam from the axis and a second deflection unit for deflecting the primary beam back towards the axis.

In that arrangement, the normal set-up of a scanning electron microscope is maintained i.e. source and specimen are arranged above each other on a straight line, the optical axis. The provision of two deflection units, one for deflecting the primary beam from this axis and the other one for deflecting the beam back towards the axis allows for a correction of imaging defects by properly selecting

parameters e.g. angles, distances, electrical and magnetic fields. Subsequently, the redirection unit directs the beam back onto the optical axis. By a proper selection of the nature of the redirection fields, a better separation of primary and secondary particles is possible which will be explained further down.

In this embodiment, the primary beam runs above and below the deflection and redirection units along a center line (the optical axis) which suppresses imaging defects caused by a non-axial propagation of the beam in electron optical components such as condenser and objective lens.

Preferably, the first (if two deflection units are used) and/or only or second deflection unit are electrostatic. It is also preferred, that the first (if two deflection units are used) and/or only or second deflection unit are magnetic. In general, all combinations or superposition of deflection fields are possible. Some of them and some combinations have particular advantageous which will be explained further down. Care should be taken, however, that the selected combinations respectively superpositions are simple and not as complicated as a Wien filter which, according to the invention, shall be avoided.

Preferably, the redirection unit is magnetic and/or electrostatic. A magnetic redirection unit, in particular, separates secondary and primary beam into complementary parts. According to Lorentz Law, secondary particles which fly in a direction opposite to the direction of the primary particles experience an opposite force. In other words, they are directed into a region which is complementary to the region of the primary particle beam.

In case the redirection unit is electrostatic, the secondary particles are directed into the region defined by the primary particle beam. However, the angle of redirection of the secondary particles is bigger since the angle of redirection is inversely proportional to the velocity. This results in a directional separation of the secondary particles from the primary particles.

In particular, it is preferred to use a second electrostatic deflection unit and a magnetic redirection unit. Thereby, the detector is located above the second deflection unit. As explained, the magnetic redirection units directs the secondary beam into a region complementary to the one of the primary beam and diverges

from it. The second electrostatic deflection unit additionally deflects the secondary beam resulting in an even bigger separation.

It is preferred to separate the first deflection device from the second deflection device and/or the second deflection device from the redirection unit. This way, the particles in the primary and secondary beam can travel longer distances before they change their path again and thus achieve bigger distances from the optical axis and from each other. Consequently, it is easier to locate the detectors so that only secondary particles are detected.

In even more preferred embodiments, the first deflection is magnetic since magnetic deflection devices are easier to accomplish.

Preferably, an opposing field spectrometer is arranged before the detector. Due to the complete separation of secondary particles, additional analytical elements such as an opposing field spectrometer can be used.

The invention is also directed to methods by which the described apparatus operates. It includes method steps for carrying out every function of the apparatus. These method steps may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention is explained with respect to preferred examples and with reference to the accompanying drawings which will be explained in the following in further detail. Thereby,

Fig. 1 shows a first embodiment according to the invention with two deflection devices and a redirection unit.

Fig. 2 shows a second embodiment according to the invention with one deflection device and a redirection unit. The primary beam above the deflection device is shifted parallel to the optical axis.

Fig. 3 shows a third embodiment according to the invention with one electrostatic deflection device and a magnetic redirection unit. The primary beam above the deflection device is shifted parallel to the optical axis.

Fig. 4 shows a fourth embodiment according to the invention with two deflection devices and a redirection unit. The second deflection device is electrostatic and the redirection unit is magnetic.

Fig. 5 shows a fifth embodiment according to the invention in which the particle source and a part of the optical devices are tilted with respect to the optical axis.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows the primary particle beam, propagating along optical axis A, which comes from its source and subsequent optical devices (e.g. Cathode, Wehnelt assembly, Wehnelt cup, anode and condenser lens) all of which being denoted with reference sign 2.

A first deflection unit 52, magnetic and/or electrostatic, deflects the beam from optical axis A. "Optical axis" is understood as axis (in general defined by the optical axis of the objective lens) along which the primary electron beam would propagate without the deflection and redirection units of the invention. The first deflection unit 52 deflects the beam from the optical axis and the second magnetic and/or electrostatic deflection unit 54 deflects it back so that it runs diagonally to the optical axis. Redirection unit 56 directs the primary particle beam back into optical axis A and, subsequently, it propagates along a path which it would have taken without deflection units 52 and 54.

The primary electron beam is guided through objective 24 and impinges in known manner onto specimen 26. Scanning electron microscopes comprise additional scanning elements not shown in the drawings. When the primary

particle beam impinges onto the specimen 26, secondary particles e.g. secondary electrons or backscattered electrons are created and appropriate devices accelerate them in direction of the objective lens which bundles them. Secondary particles in the vicinity of optical axis A will enter magnetic redirection unit 56 and will be guided, according to Lorentz law, in the region complementary to the one occupied by the primary particles. Detector 14 is arranged in the region of the secondary particles so that they impinge onto same. In the inventive arrangement it is possible to use e.g. a opposing field spectrometer.

In the embodiment shown in fig. 1, it is possible to replace the magnetic redirection unit 56 with an electrostatic one. In this case, the secondary particles are directed into the same region from which the primary particle beam is coming from. However, the angle of redirection of the secondary particles is bigger since the angle of redirection is inversely proportional to the velocity. This results in a directional separation of the secondary particles from the primary particles.

Fig. 2 shows in principal the embodiment of fig.1. However, the primary particle beam PE when coming from source 2 is not aligned but shifted parallel with respect to optical axis A defined by objective lens 24. Deflection unit 54 deflects the particle beam so that it propagates towards optical axis A and diagonal thereto. In this preferred arrangement, a first deflection unit 52 which would deflect the primary beam from optical axis A is not required. Nevertheless, the primary beam propagates still a certain distance diagonal to the optical axis before redirection unit 56 directs it back onto it prior to passing through objective lens 24. Here again, redirection unit 56 is preferably electrostatic which entails the above described consequences.

The embodiment of fig. 3 comprises one deflection device 54 and a redirection unit 56. Source 2 is located so that it emits a primary beam which propagates parallel to the optical axis of the objective lens 24. In this preferred embodiment, deflection device 54 is electrostatic and the redirection unit is magnetic. Consequently, secondary particles coming from specimen 26 are guided by the redirection unit into a direction different to the direction of the incoming primary beam. This initial separation is emphasized by deflection device 54 which acts, due to their slower velocity, stronger on the secondary than on the

primary particles. In this embodiment, the detector is preferably arranged above deflection device 54.

In certain applications, it is desirable to align particle source 2 and objective lens 24 on one axis. Such an arrangement is shown in fig. 4. In order to still make use of the present invention, it is preferred to provide a first deflection unit 52 for deflecting the primary beam from the common axis. The remaining parts of the shown embodiment are identical with those described in fig. 3. The second deflection unit 54 is electrostatic and redirection unit 56 is magnetic again. This results in respective paths of primary and secondary electron beams. Even so the first deflection device can be either magnetic or electric, it is preferred to use magnetic ones since, from a constructional point of view, they are easier to accomplish.

In the embodiment shown in fig. 5, same reference numbers relate to same or corresponding parts. The part of the beam path which runs diagonally to optical axis A is obtained by tilting the devices and parts denoted with reference number 2 which represent the particle source. Thus, deflection units 52 and 54 are not needed since the primary beam already enters redirection unit 56 at a certain angle which allows easier separation of primary and secondary particles. It is within the scope of the present invention to tilt the upper part of the beam column or the source respectively emitter chamber with respect to the optical axis defined by the objective lens. Alternatively, it is possible to tilt the objective lens with respect to the beam column. The tilting can be accomplished by the carrier frame of the beam column or by accommodating the respective parts tilted within the carrier frame. In certain cases, the mechanical tilting of the beam path might result in less quality optical imaging due to the lack of correction options, however, fewer electromagnetic deflection devices are needed to carry out the invention. In embodiments with mechanically tilted primary beam paths, all kind of redirection units, electric and/or magnetic, can be used. In preferred embodiments, a magnetic redirection unit is used.

In all figures an opposing field spectrometer 15 is advantageously arranged in front of the detectors. The concept of the invention can, of course, also be carried out without such a spectrometer. In preferred embodiments, the redirection unit is located above the objective lens. This allows easier

accommodation of the redirection unit and provides better separation between primary and secondary particles.

The redirection unit shown in the above described figures is arranged so that it can redirect both, primary and the secondary particles. If, in the context of this description, a deflection device or the redirection unit is quoted as being electrostatic or magnetic then it is meant that these devices and units are capable of producing a respective field which acts on the charged primary and secondary particles.

It should be noted that radial dimensions and deflection angles shown in the figures are exaggerated for demonstrative purposes. Further, without limiting the scope of claims, the actual beam deflections are simply indicated by a kink. Also, in all figures it is assumed that the charges of the primary and secondary particles are of the same polarity. Should it be required to detect secondary particles having a polarity opposite to the primary particles then the respective positions for the detectors or the respective field directions of the deflection devices and the redirection unit have to be adapted accordingly.

The above described principal of the invention is not limited to scanning microscopes but can be carried out in all kind of charged particle beam devices.

CLAIMS

1. Particle beam apparatus comprising:
a source (2) for providing primary particles in a primary beam;
a particle optic (24) for guiding particles from the source (2) onto the specimen (26);
a secondary particle detector (14) arranged outside the primary particle beam path;
characterized in comprising
deflection devices (52, 54) causing the primary particle beam to run diagonally to optical axis (A);
a redirection unit (56) below the detector for redirecting the primary particle beam into optical axis (A); whereby
at least one of devices (52, 54) and/or redirection unit (56) is magnetic or electrostatic magnetic.

2. The particle beam apparatus according to claim 1, whereby redirection unit (56) is magnetic or electrostatic magnetic.

3. The particle beam apparatus according to any of the preceding claims, whereby at least part of the primary beam path before redirection unit (56) is parallel to optical axis (A); and whereby
deflection device (54) deflects the primary beam from said parallel path to run diagonally to optical axis (A).

4. The particle beam apparatus according to any of the preceding claims, whereby the primary beam coming from source 2 essentially propagates in optical axis (A); and whereby deflection devices (52,54) comprise
a first deflection device (52) for deflecting the primary beam from optical axis (A); and
a second deflection device (54) for deflecting the primary beam back to run diagonally to optical axis (A).

5. The particle beam apparatus according to any of the preceding claims, whereby the (first) deflection device (52) and/or (second) deflection device (54) is electrostatic.

6. The particle beam apparatus according to any of the preceding claims, whereby the (first) deflection device (52) and/or (second) deflection device (54) is magnetic.

7. The particle beam apparatus according to any of the preceding claims, whereby the second deflection unit (54) is electrostatic and redirection unit (56) is magnetic; and whereby
detector (14) for secondary particles is arranged above second deflection unit (54).

8. The particle beam apparatus according to claim 7, whereby the first deflection unit (52) is magnetic.

9. Particle beam apparatus comprising:
a source (2) for providing primary particles in a primary beam;
a particle optic (24) for guiding particles from the source (2) onto the specimen (26);
a secondary particle detector (14) arranged outside the primary particle beam path;
characterized in that
said source (2) is tilted with respect to optical axis (A) causing the primary particle beam to run diagonally to optical axis (A);
a redirection unit (56) below the detector for redirecting the primary particle beam into optical axis (A).

10. The particle beam device of claim 9, wherein the redirection unit is magnetic or electrostatic magnetic.

11. The particle beam apparatus according to any of the preceding claims, whereby an opposing field spectrometer is arranged in front of detector (14).

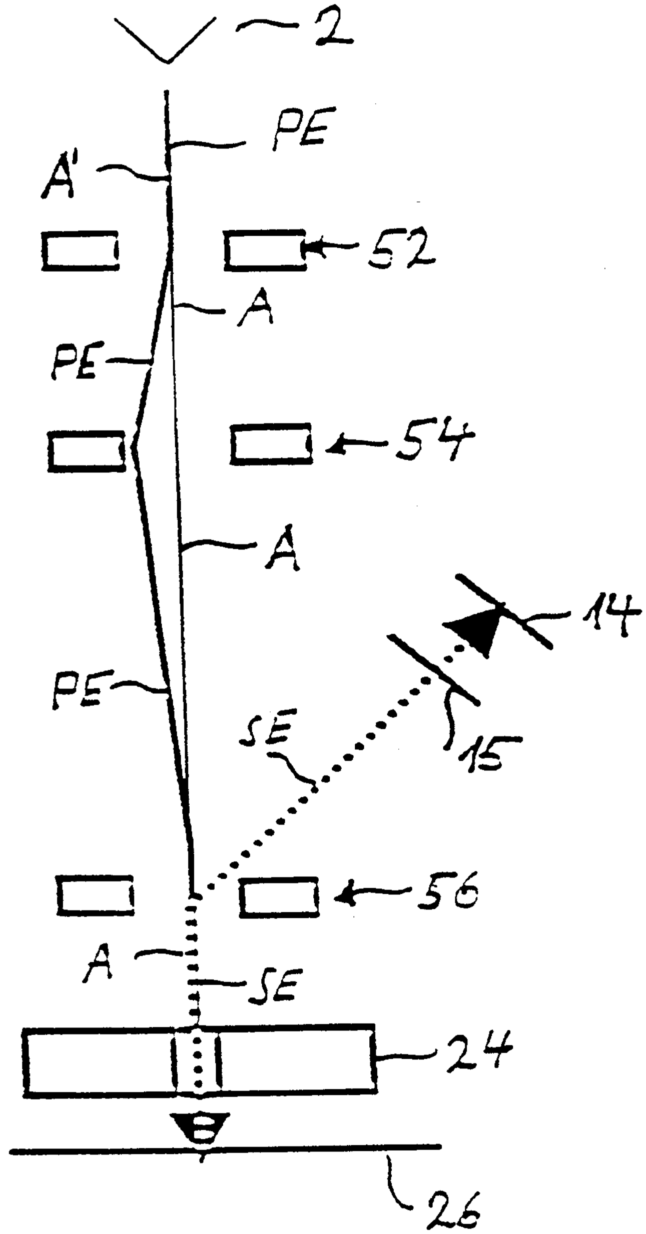


Fig. 1

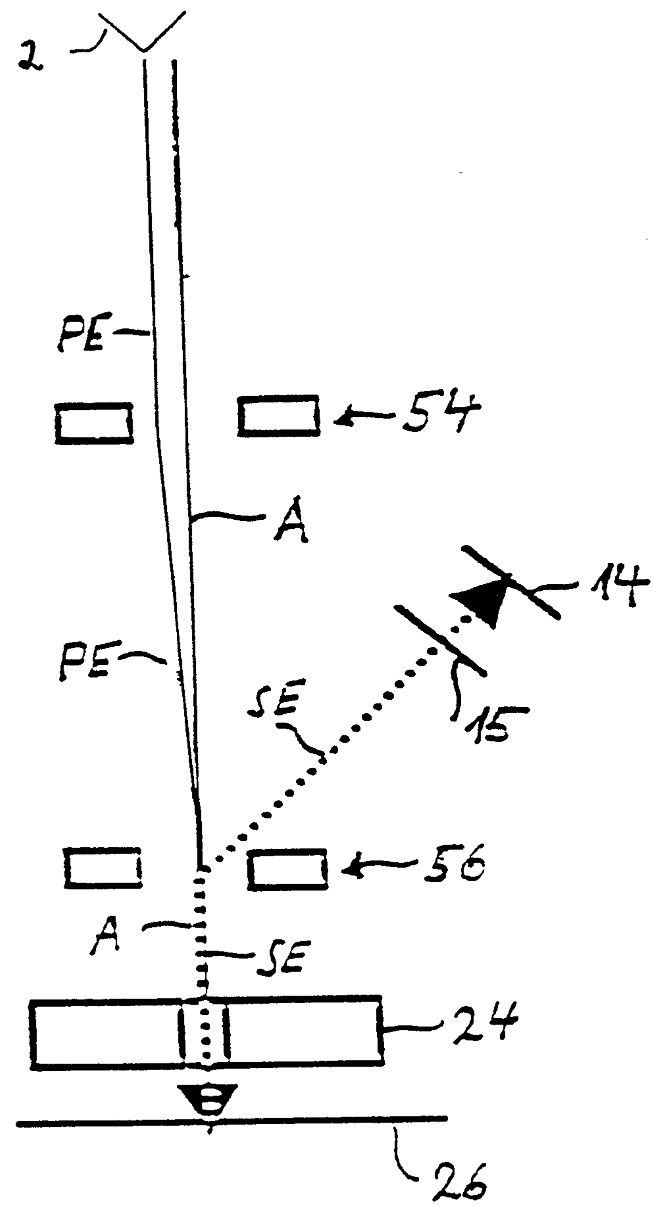


Fig. 2

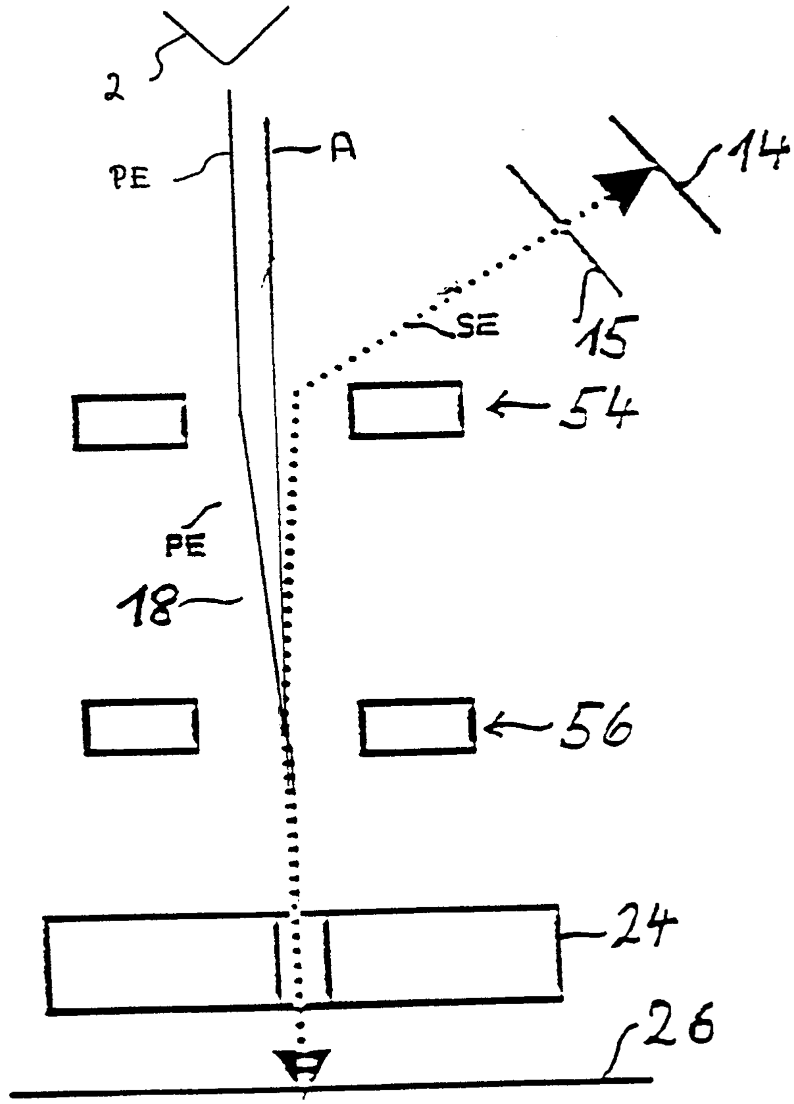


Fig. 3

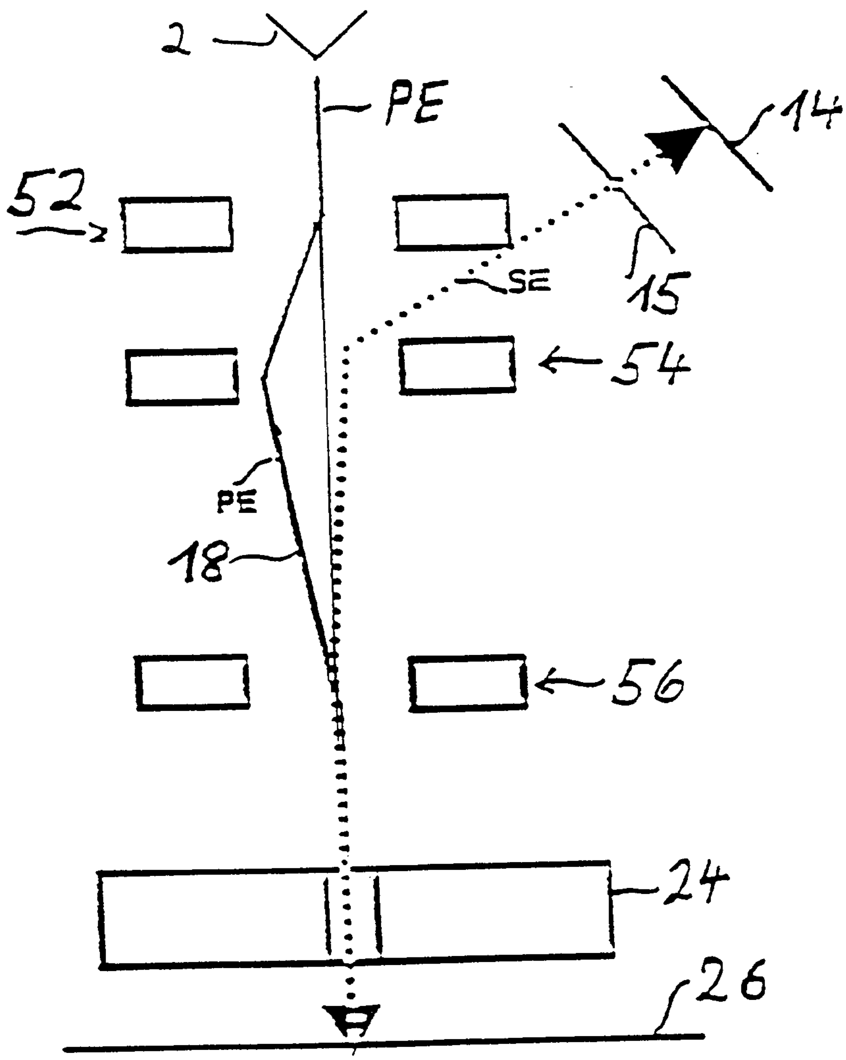


Fig. 4

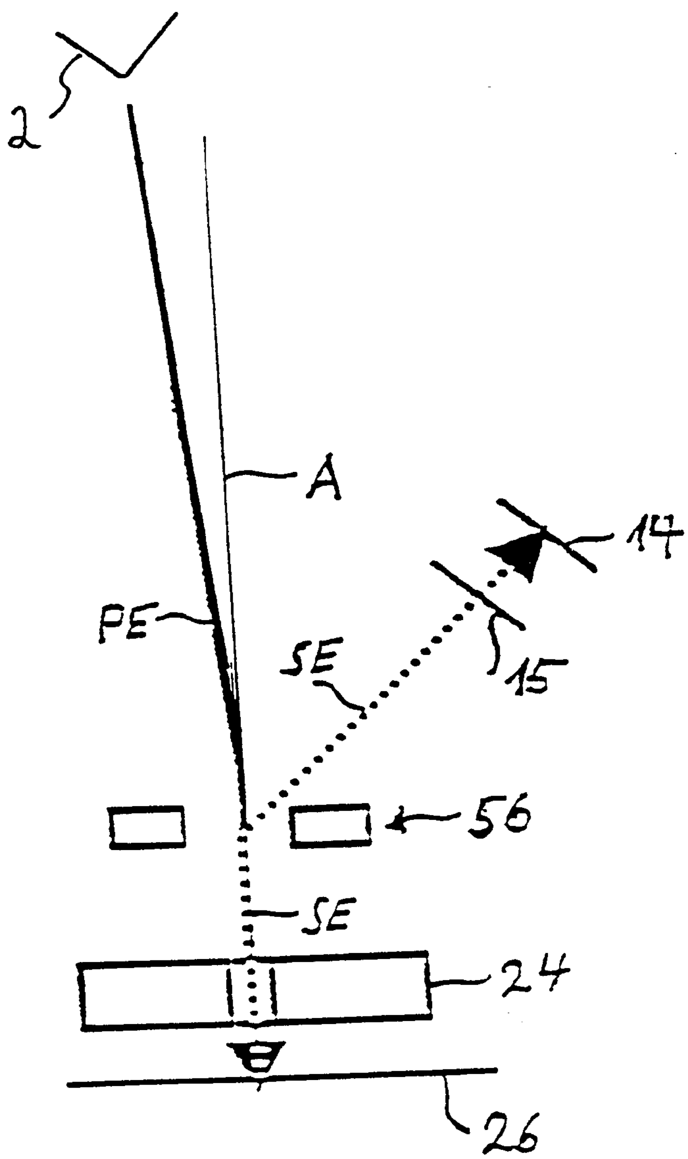


Fig. 5

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 98/07381

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01J37/04 H01J37/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 95 26041 A (PHILIPS ELECTRONICS NV ;PHILIPS NORDEN AB (SE)) 28 September 1995 see page 2, line 20 - page 3, line 16 see page 5, line 9 - page 6, line 8; figures 2,3 ---	1,3-5
A	DE 42 16 730 A (INTEGRATED CIRCUIT TESTING) 25 November 1993 see abstract; figures ---	1
A	US 5 483 065 A (SATO MASAO ET AL) 9 January 1996 see abstract; figures -----	1,9

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 March 1999	25/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schaub, G

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 98/07381

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9526041 A	28-09-1995	DE 69501533 D	05-03-1998
		DE 69501533 T	30-07-1998
		EP 0699341 A	06-03-1996
		JP 8510596 T	05-11-1996
		US 5510617 A	23-04-1996
DE 4216730 A	25-11-1993	US 5422486 A	06-06-1995
US 5483065 A	09-01-1996	JP 7110310 A	25-04-1995